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## MOVEMENTS OF DIATOMS AND OTHER MICROSCOPIC PLANTS.

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FEW subjects in the domain of cryptogamic botany have given rise to more speculation and conflicting theories than have the studies into the cause of the apparently voluntary movements of diatoms. From time to time for the past twelve years the author has been confronted with this seemingly fruitless subject, and only recently, almost by accident, has the problem been solved.

It was early shown by examination in closed cells that the phenomenon was not due to external currents set up in the surrounding liquid, but that the power of motion came from the organism itself. Largely on account of these movements, which appeared to be spontaneous and voluntary, the diatoms were originally classed in the animal kingdom.

The first theory which naturally presented itself was that they move as do the Infusoria by means of vibrating hair-like cilia or flagella. Later certain authors claimed to have seen protoplasmic processes similar to those of the rhizopods protruding from the small openings in the frustule of the organism. Then came the theory of Onderdonk<sup>1</sup> which described the progression as due to a thin fluid mass in rhythmical motion covering the surface of the diatom.

Nägeli suggested that the motion is due to endosmotic and exosmotic currents, and H. L. Smith<sup>2</sup> after much study of the subject came to the conclusion "that the motion of the Naviculæ is due to injection and expulsion of water, and that these currents are caused by different tensions of the internal membranous sac in the two halves of the frustules."

<sup>1</sup> The Movements of Diatoms. *The Microscope*, August, 1890.

<sup>2</sup> A Contribution to the Life History of the Diatomaceæ. *Proc. Amer. Soc. Microscopists*, 1888.

In order to prove this theory, Professor Smith showed by means of suspended indigo that when the diatom moves forward the particles of indigo gather around the central nodule of the valve and form a small mass which turns on itself just as if it was impelled by a jet of water proceeding from the valve at this point. Each of these little turbulent spheres after having acquired a certain size, falls apart and the particles which compose it are driven along the valves from front to back and accumulate behind the extremity of the frustule which, according to its progression, would be considered the rear. The particles move as if they were subjected to a current going from front to back, and reverse when the motion is reversed. That these currents exist there can be no doubt, but that the motive power is not due to the expulsion of water will shortly be demonstrated.

The first intimation of the true nature of this motion was suggested by the action of a lithia tablet in a glass of water. The bubbles of carbonic-acid gas given off set up the exact motions in the tablet that have been so often described for the movements of diatoms: "A sudden advance in a straight line, a little hesitation, then other rectilinear movements, and, after a short pause, a return upon nearly the same path by similar movements."

Repeated experiments with compressed pellets evolving gas have shown that this is the usual motion produced by the evolution of gas bubbles, and when pellets were made of the same shape as *Navicula* the movements of these diatoms were perfectly duplicated. Boat-shaped pieces of aluminum two millimeters thick were then made and on them were cut longitudinal grooves to resemble those of the diatom. When placed in strong caustic soda solution the movements of the metal produced by the evolution of hydrogen gas again duplicated those of the diatom in a remarkable manner. The metal having the grooves had a greater power of motion than that without the grooves.

If we consider that the diatom contains chlorophyll bands which when exposed to a strong light rapidly evolve oxygen, and if we take into account the fact that the motion does not take place unless the light is fairly strong, we have then a conception of the true nature of the movements of these organisms.

Streams of oxygen may be readily seen evolving from all parts of many of the larger aquatic plants when submerged in water and exposed to strong light, but in the diatom while the gas produced is large in amount compared with the size of the organism, the actual amount evolved is so small that it is taken into solution almost immediately. That such evolution takes place, however, is shown by Professor Smith's experiments with indigo. If now we examine the artificial diatom made of aluminum and placed in strong caustic solution we find that the bubbles from all sides come together and rise in a line corresponding to the median line or raphe of the organism, and that if indigo is placed in the liquid it collects and rotates near the central nodule just as described by Professor Smith to prove his theory of the presence of water currents.

It is therefore evident that the motion of diatoms is caused by the impelling force of the bubbles of oxygen evolved, and that the direction of the movement is due to the relatively larger amount of oxygen set free first from the forward and then from the rear half of the organism. This accounts for the hesitancy and irregular movements as well as the motion forward and backward over the same course.

The evolving gas seems to act at times as a propeller to push the organism forward and at other times to exert a pulling action to raise the growth on end. The various movements described are the resultants of varying proportions of both of these active forces.

The fact that a longitudinal groove on the under side of the artificial diatom causes it to become more active, due to the expulsion of the gas along the line of the groove, explains the greater activity of the Raphideæ.

The most interesting and peculiar movements among diatoms are those of *Bacillaria paradoxa* whose frustules slide over each other in a longitudinal direction until they are all but detached and then stop, reverse their motion and slide back again in the opposite direction until they are again almost separated. When the diatoms are active, these alternating movements take place with very considerable regularity. It is probable that the indi-

loosely than other laterally attached genera and that when a forward movement takes place in the outer individual it is arrested by capillarity just before the diatom is completely detached.

It can now be readily seen that the strange movements of the other microscopic plants may be explained as also due to the evolution of oxygen gas. While the movements of desmids are not as strongly marked as those of diatoms, many of them, notably *Penium* and *Closterium*, have often been described as having a power of independent motion, and Stahl<sup>1</sup> found that this motion is greatly affected by light.

The best account of the movements of desmids has been given by Klebs.<sup>2</sup> This author speaks of four kinds of movements in desmids, *vis.*:—

(1) A forward motion on the surface, one end of each cell touching the bottom, while the other end is more or less elevated and oscillates backwards and forwards.

(2) An elevation in a vertical direction from the substratum, the free end making wide circular movements.

(3) A similar motion, followed by an alternate sinking of the free end and elevation of the other end.

(4) An oblique elevation, so that both ends touch the bottom—lateral movements in this position; then an elevation and circular motion of one end, and a sinking again to an oblique or horizontal position.

This observer considered these movements to be due to an exudation of mucilage, and the first two to the formation, during the action, of a filament of mucilage by which the desmid is temporarily attached to the bottom and which gradually lengthens.

These four kinds of movements are very easily explained by the theory of the evolution of gas, and by regulating the conditions they can be exactly reproduced in the artificial desmids made of aluminum. In this case strips of thin aluminum foil should be used. When the gas production is very strong at one

<sup>1</sup> *Verhandl. phys. med. Gesellsch. Würzburg*, 1880, p. 24.

<sup>2</sup> *Biol. Centralblatt*, 1885, p. 353.

end, the desmid will be raised to a vertical position and will take up oscillating or circular movements.

If we now pass to a consideration of like movements in the Cyanophyceæ, the same explanation holds true for *Oscillaria* which often takes up a waving or circular motion when attached at one end. This movement is well described by Griffith and Henfrey<sup>1</sup> as follows: "The ends of the filaments emerge from their sheaths, the young extremities being apparently devoid of their coat; their ends wave backward and forward, somewhat as the forepart of the bodies of certain caterpillars are waved when they stand on their prolegs with the head reared up." The authors attribute this motion to "irregular contraction of the different parts of the protoplasm."

The free-swimming species of *Nostoc* all have a spontaneous power of active motion in water, and in all of the filiform orders of the Cyanophyceæ, detached portions of the filament known as hormogones also have the power of spontaneous motion. All of these movements can be exactly duplicated with lithia tablets in water or with aluminum of the proper weight and shape immersed in strong caustic solution, and are also undoubtedly caused by the strong evolution of oxygen gas due to the activity of the chlorophyl present in the organisms.

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<sup>1</sup> *Micrographic Dictionary*, p. 561.